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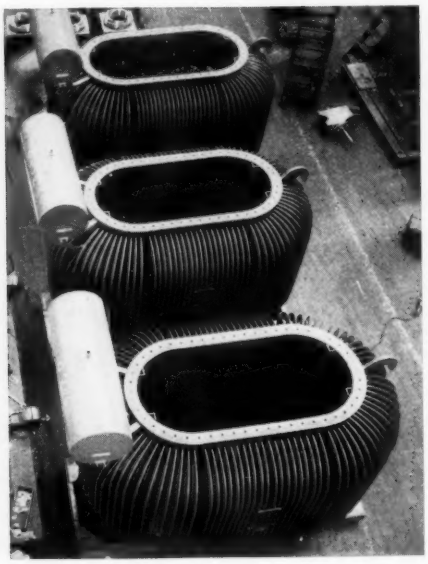

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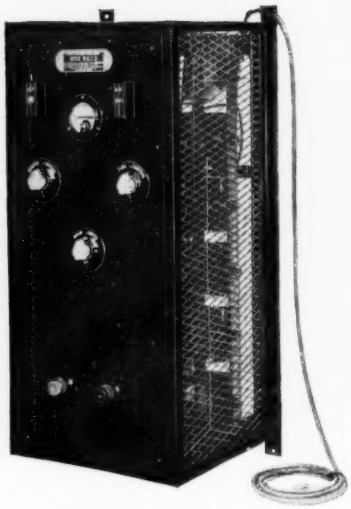

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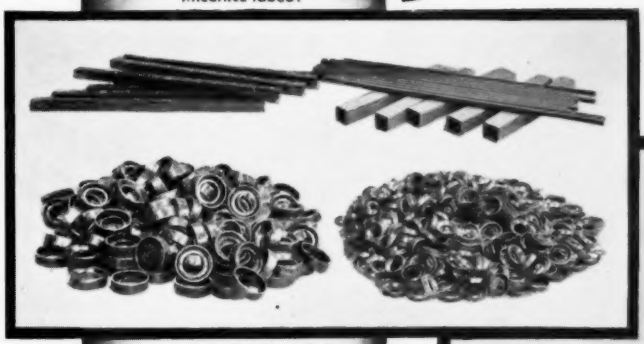

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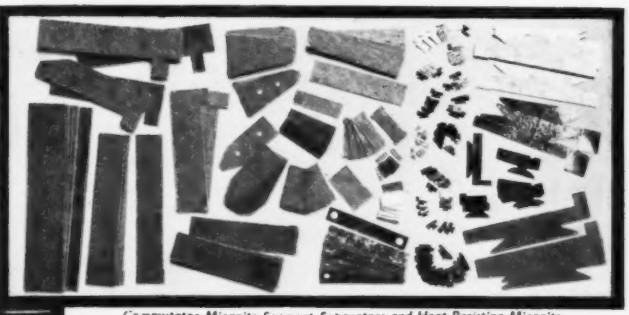

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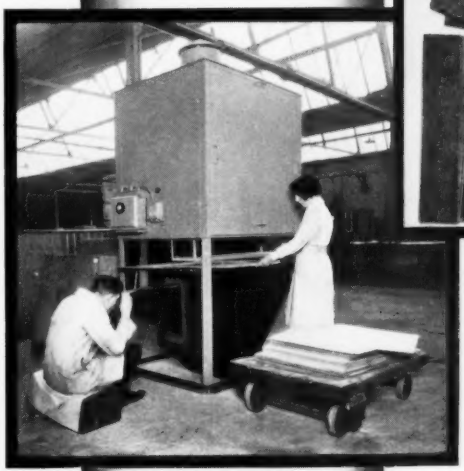

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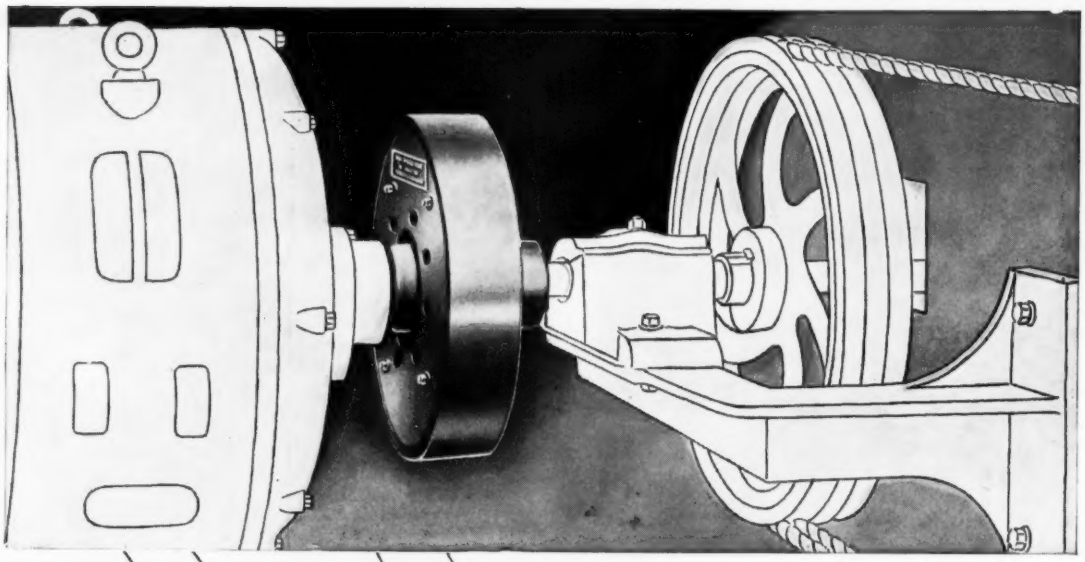

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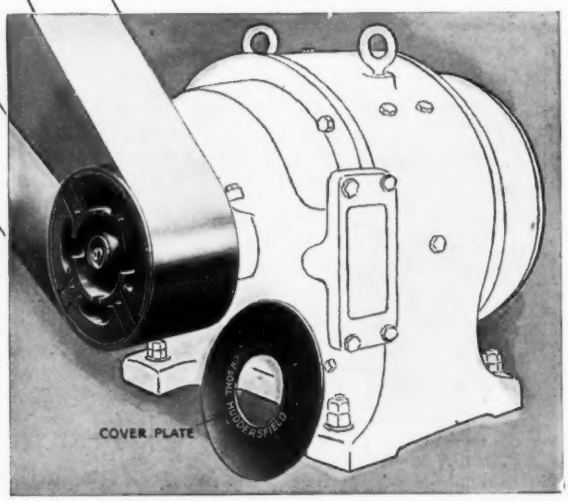

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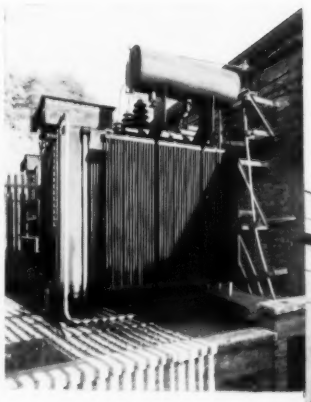

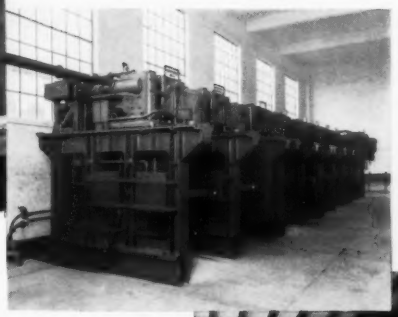

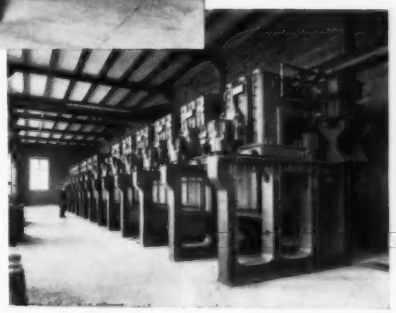

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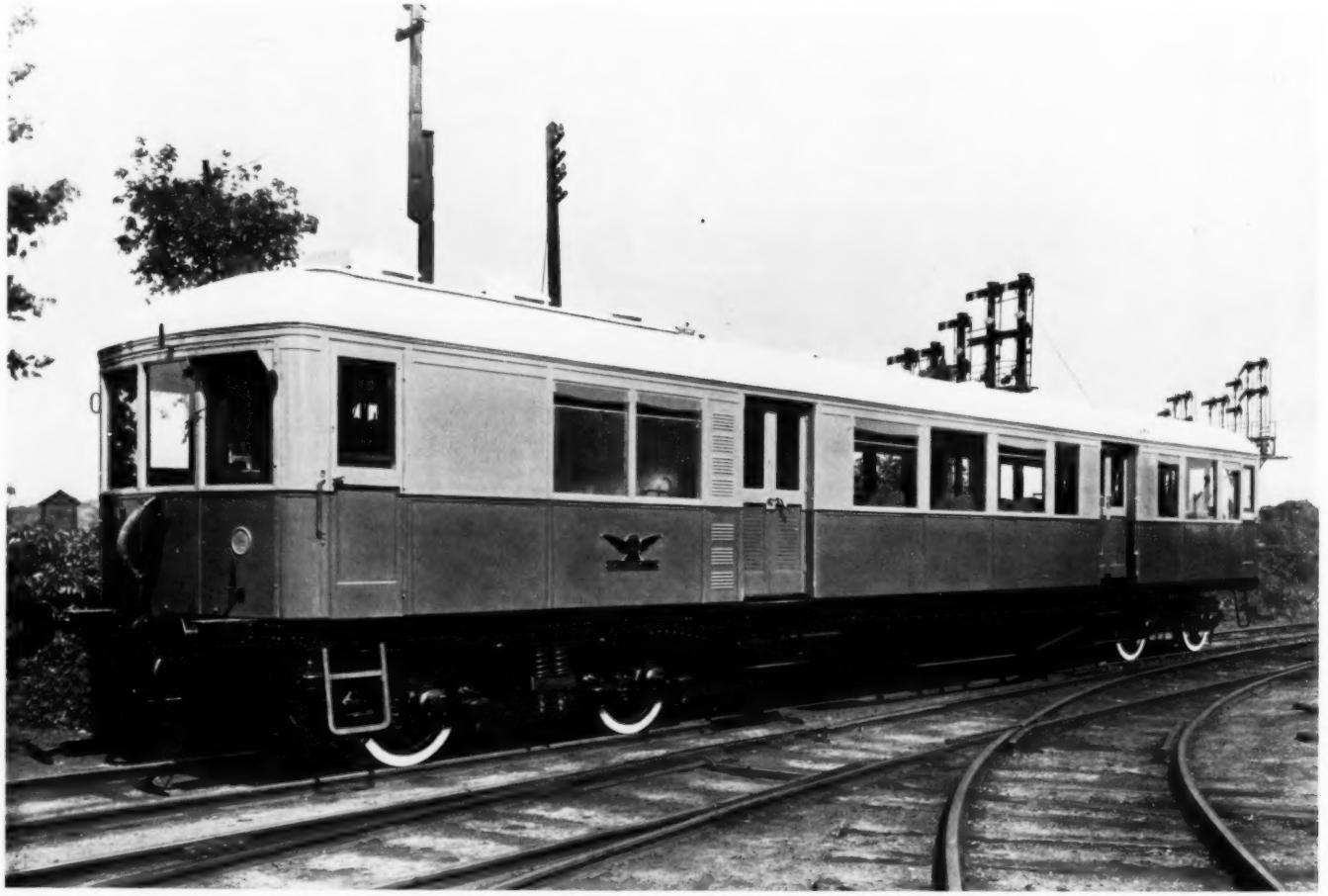

200 h.p. Diesel Electric Rail Coach.

The English Electric Journal

Vol. VI. No. 7 DECEMBER, 1933 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

It will be noted that the greater part of this issue of the Journal has been devoted to an article by Mr. J. E. Calverley on the principles involved in the Grid Control of Mercury-Arc Rectifiers. Grid Control has extended very greatly the field of application of the rectifier, and we direct our readers' attention to the many possibilities briefly referred to towards the conclusion of the article.

The Company is exceptionally well placed in being able to incorporate in its rectifiers the very latest developments, having at its disposal the resources of a large research organisation.

The article is introductory to other articles that we contemplate for future issues of the Journal. These will deal with various special features of Rectifier work, as for instance, a method of control

for Railway systems on which regenerative working is required, and will also include descriptions of plants that have been installed and are in operation. We trust that the articles as a whole will be of considerable interest at the present time when Mercury Arc Rectifiers are so much to the fore, and development work in this field is proceeding so rapidly.

The concluding article describes the new 200 h.p. Diesel-Electric Rail Coach for branch line working that the Company has recently designed and built. The coach was first tried out on the Company's test track at Preston, and since then, thanks to the courtesy and co-operation of the L.M.S. Railway, it has been run under service conditions on the Warwick/Northampton branch and on the Watford/St. Albans line, where it is at present in service.

The English Electric Company has had many years' experience of vehicles with internal combustion engines, and these vehicles are in service in many parts of the world.

The new Rail Coach has been designed, built, and equipped entirely in the Company's own Works, the coach and bogies coming from Preston, the engine from Rugby and the electrical equipment from the Bradford Works.

Contract for Turbo-Alternator Plant.

In connection with the large extensions which are now being made to Messrs. Edward Lloyd's Kemsley Paper Mills, the Company have been awarded contracts for three Turbo-Alternator Sets, comprising :—A 15,000 kW. two-cylinder, 3,000 r.p.m., Pass-out Turbine, believed to be the largest machine of this type yet to be constructed in this country. It will generate power and supply process steam up to 240,000 lbs. of steam per hour at a pressure of 20-30 lbs. per sq. inch gauge, to the largest newsprint machine in course of construction.

A 500 kW. Pass-out Single Cylinder Turbine at 3,000 r.p.m. to pass out up to 150,000 lbs. of steam per hour, at a pressure of 20-30 lbs. per sq. inch gauge.

The alternators for the two above-mentioned sets will generate power at 6,600 volts, 50 cycles, 3-phase.

Also a 750 kW. Single Cylinder Geared House Set, running at 7,000 r.p.m., the alternator being geared down to 1,500 r.p.m. and generating power at 430 volts, 50 cycles, 3-phase.

British Industries Fair, Birmingham. February 19th to March 2nd, 1934.

A cordial invitation is extended to all our readers to visit the Company's stand, No. E.311, in the Electrical Section of the Fair. Exhibits will include a wide range of industrial fuse gear, domestic, heating and cooking appliances, including electric fires, cookers, water heaters, and A.C. and D.C. Fractional H.P. Motors.

The Grid-Controlled Mercury-Arc Rectifier and The Principles Involved.

Reprint of a Paper read on the 5th December, 1933, before the Institution of Electrical Engineers, East Midland Centre.

By J. E. CALVERLEY, M.I.E.E., Chief D.C. Designer.

The general principles underlying the operation of the mercury-arc rectifier are now becoming well understood by engineers, and developments in rectifier construction and control are taking place with amazing rapidity. The most important development lies in the control of the arc discharge by polarised grids in the arc path. It has given rectifiers many new possibilities, and opened up fields for their application which were previously closed to plant of this type.

Until quite recently the rectifier was little more than a switch connecting the phases of the transformer in circuit with the D.C. load in their correct sequence, when their voltage waves were near the peak and of the correct polarity. It could offer no control of the current flow or voltage. Polarised grids have eliminated these disadvantages and endowed the rectifier with control of the voltage by introducing only one additional feature—the possibility of igniting the arc at any required point in the voltage cycle.

An alternating current wave offers all values of voltage from zero to its maximum in each direction as it passes through its cycle, and the rectifier is enabled to select any part of the wave and include it in the D.C. circuit.

In a rectifier of normal construction without polarised grids, the commutation of the current takes place naturally from anode to anode, as determined by the sequence of the phases. The arc will exist only on the anode or anodes, which are at a potential slightly above the cathode potential. The difference in these potentials is the internal voltage drop in the rectifier, and varies from about 15 volts on a small glass bulb to over 30 volts on the largest steel-tank unit. The arc consists largely of electrons, which, being of negative polarity, travel in the direction from negative to positive along the di-electric field. It is the action of these minute charges 629×10^{16} per second of which are required to make up 1 ampere, which gives the arc its rectifying properties.

In dealing with rectifier problems it must be kept clearly in mind that the movements of electrons is in the opposite sense to the accepted direction of the current flow.

When the rectifier is in operation, the cathode emits enormous quantities of electrons, and others are produced from the mercury atoms by collision. They stream along the di-electric fields in the vacuum chamber towards any part which is at positive potential, and which can absorb them. A part which absorbs electrons acquires a charge, and if this can be carried away by current to an external circuit, electrons will continue to flow at a rate which leaves the part or anode at a potential just sufficient to maintain their flow from the cathode. If the circuit is interrupted, electrons will be absorbed until the anode is charged to the same potential as the cathode, and the arc will be discontinued. On the other hand, surfaces of negative potential repel the electron stream, and in these phenomena resides the valve action of the rectifier.

At the cathode surface the electrons receive their freedom of movement, and this is the datum line of potential on which all voltage relations in the rectifier are founded.

Fig. 1 shows in diagram form the potential distribution in the rectifier and its external circuit for a 6-phase unit delivering its output at 100 volts D.C. with 25 volts arc drop. This would be inefficient, but the values chosen provide a good diagram. It will be noted that the average anode positive potential is very close to the peak value

of the anode voltages, and the cathode potential is slightly lower. Consequently, electrons are repelled from all the anodes except those which are near the peak of their positive half cycle. All those anodes which at any instant are below the datum line of cathode potential, repel the arc, and it is immaterial whether they are momentarily on their positive or negative half cycles. As the voltage of the anode rises above cathode potential, the arc is formed on it or transferred from the last anode in the sequence, the potential of which is falling below that of the cathode. The whole operation of the arc is, therefore, determined by the potential of the cathode relative to all other conducting parts of the circuit. This conception

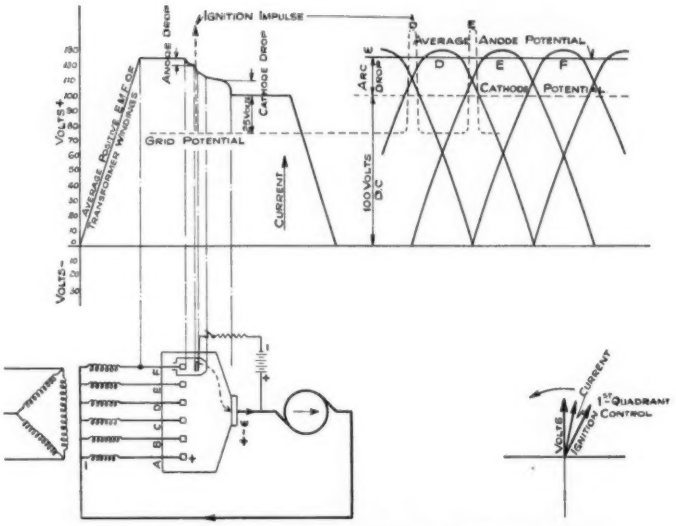


Fig. 1. Voltage Distribution in Rectifier and its External Circuit during Rectification.

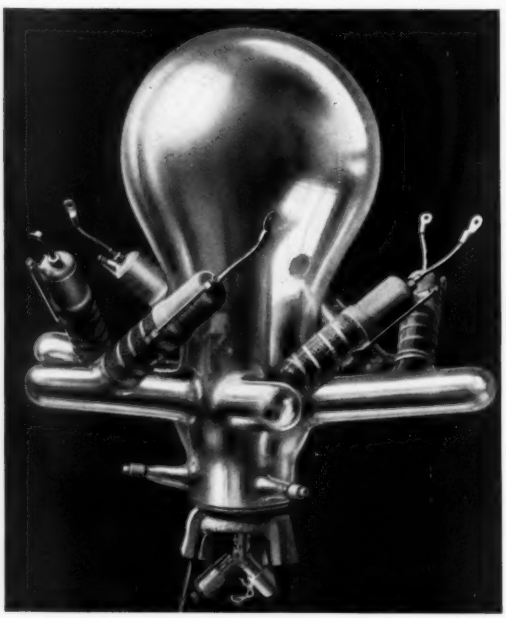


Fig. 2. Glass Bulb Rectifier with Control Grids.

of the conditions which govern commutation or arc transfer, though generally correct, is very imperfect, because it ignores the effect of positive ions, but is sufficiently complete to enable us to study the action of the control grids.

In service the anodes are never more than 15 to 40 volts positive relative to the cathode, and this E.M.F. provides a di-electric field of sufficient intensity to build up and maintain the arc. The length of the arc varies with the size and voltage of the unit and in some cases has a length of 40 to 50 inches. A good vacuum is necessary to allow the electrons free motion, or, in other words, to maintain the arc drop at a reasonable value. Of the total arc drop 3 to 5 volts are lost at the surface of the anode, and about 7 to 10 volts are lost on the surface of the mercury cathode, the remainder of the loss, say, 5 to 15 volts, is expended in the arc; a small portion of the voltage loss provides the energy to commutate the arc from anode to anode. These figures give an indication of the comparatively weak di-electric field which is necessary for the control of the arc, and it will be obvious that counter-fields or cross-fields can be superimposed for control purposes with the aid of comparatively small voltages and very little loss of energy. If the anode is enclosed

in a screen or grating, commonly called a "grid," in such a way that the arc, when formed, must pass through its meshes, it can be used to mask the anode potential and impose its voltage on the di-electric field along the arc path. The grid is usually situated comparatively close to the anode, is insulated from it and from the remainder of the structure, and provided with leads brought out of the vacuum vessel through appropriate seals.

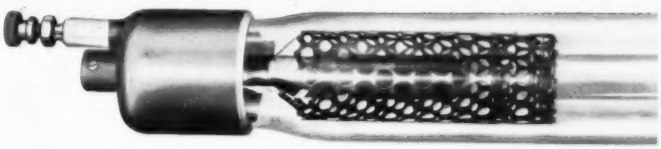


Fig. 3. Anode Arm showing Control Grid.

If we assume for the moment that the grid is connected to the cathode through a high resistance, it will be obvious that no potential will exist between these two surfaces, and that an arc will be unable to form, as there will be no di-electric field to propel the electrons from cathode to anode. Under these conditions the rectifier will be entirely non-conducting.

In practice the grid is made to repel the arc during the impermeable period, and for this purpose is given a negative potential relative to the cathode, with the aid of a battery or small rectifier. The grid requires very little power to charge it up to any required potential, and the charging current is of the order of a few milli-amperes. The value of the grid voltage used for this purpose is not critical, but to ensure effective blocking, a voltage several times that of the arc drop is generally used, the value varying from 25 to 250 volts, depending upon the size and voltage rating of the rectifier itself.

Fig. 2a. Glass Bulb Rectifier Cubicle.

From the foregoing it will be appreciated that whilst the grid retains its negative potential relative to the cathode an arc will not form, but if the negative potential is removed, the rectifier will behave exactly as if the grid were not there, and the arc will commutate naturally. To ensure instantaneous starting of the arc at any instant other than the natural one, the grid must be given positive polarity, and for control purposes the instant at which this changeover takes place must be predetermined. If all other conditions are favourable, the arc will ignite immediately, and the grid will then lose its influence and take up the potential imposed upon it by its position in the arc. If we try to give it a negative potential whilst the arc exists, the grid will merely attract positive ions (which are present in large numbers in the arc stream) sufficient to neutralize the applied potential and render it ineffective. Actually the negative field of the grid becomes totally screened off by a very thin layer of positive ions, which prevent the grid from exerting any influence on the electrons in the discharge path ; therefore it is only possible to control the grid potential by external means during the non-conducting period of the anode.

The grids can, therefore, be used not only to prevent the arcs from starting but to start the arcs at any required instant, but once the arc has formed we have no further control over it on the anode in question. It will continue to burn until it is transferred to the next anode by commutation or until there is not sufficient potential left to maintain it. The grid on the next anode in the sequence, however, will determine the point at which its own anode takes up the load and the arc is transferred, with the result that grid control does, in effect, provide for both starting and stopping the arc of each anode.

Arrangement of Grids and Their Effect on the Rectifier Rating.

The grid-controlled rectifier differs only from its prototype in the arrangement of the arc guides and the inclusion of the control grids and their connections. Greater security of operation is attained, and the biassing potential introduces additional safeguards against backfire, together with rapid suppression if it does occur. De-ionisation is carried out more completely and in shorter time by the additional collecting surface of the grid and its connections through the control gear to the cathode, with the result that a standard rectifier, when fitted with control grids, will deliver a larger current output. The more rapid de-ionisation calls for increased excitation to maintain stability at light loads.

Fig. 2 shows a 300-ampere glass bulb rectifier with control grids, while details of the anode and grid are given in Fig. 3. A steel-tank rectifier differs, of course, in constructional details, see Fig. 4—a sectional drawing of a 2,500-ampere unit. An anode plate lifted from the vacuum vessel is illustrated in Fig. 5, while Fig. 6 shows a complete rectifier. A graphite block forming the anode is situated in the upper part of the arc guide, as shown in the sectional drawing. The arc will exist down the centre of the guide and must pass through the meshes of the grid. Usually there are one or more other grids of an open nature in close proximity to the control grid, which are necessary for de-ionisation of the arc path during the impermeable period. These, however, are not always insulated, but may form part of the arc guide itself.

During operation the grid potential approximates to that of the cathode, and on the peak of the negative voltage of the anode the space between anode and grid must withstand twice the D.C. voltage of the rectifier.

In high voltage rectifiers the voltage stress per unit length in the space between anode and grid may reach values as high as 5,000 volts per inch, and unless complete de-ionisation of the space is achieved, positive ions will be accelerated on to the anode and a backfire may result. Careful design coupled with research and experiment relating to the conditions in this space have resulted in the construction of rectifiers for voltages up to 30,000 and now rectifiers with a voltage of 50,000 appear possible.

In dealing with D.C. voltages in the industrial range, and especially the lower values, where the arc drop is an appreciable percentage, it is desirable that the cathode spot should be limited in its movements. A steel-tank rectifier to deliver

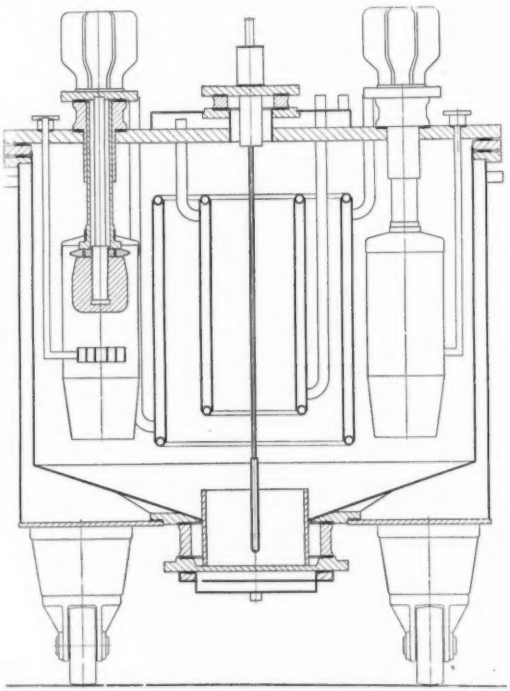


Fig. 4. Section through an "English Electric" grid-controlled steel-tank mercury arc-rectifier rated at 2,500 amperes at D.C. pressures up to 800 volts.

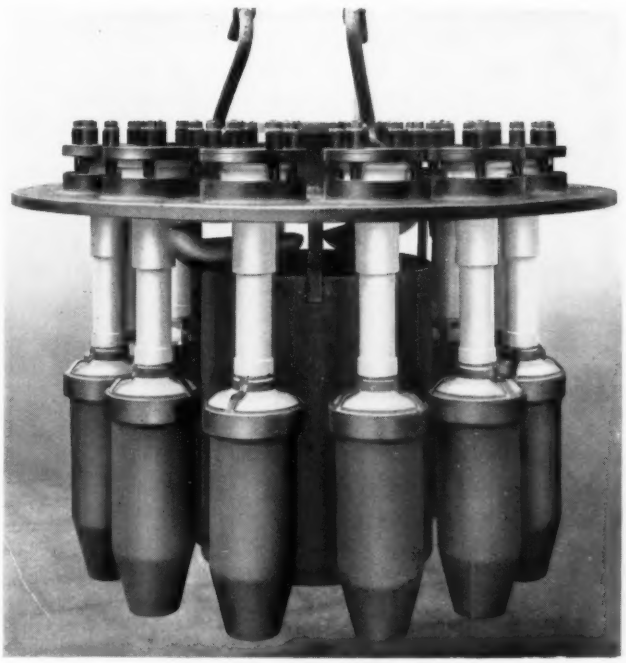


Fig. 5. Top plate of Vacuum Chamber with complete Anode Assembly and Vapour Cooler.

4,000 amperes, has an area of over 300 square inches of mercury surface, and the cathode spot wanders at random over the whole of this surface. The actual length of the arc, therefore, varies to some extent with the position of the cathode spot, and the arc drop will vary with it, rendering the value of the regulation not quite as definite as could be desired, especially if soft control is used. It is therefore good practice to limit the movement of the cathode spot with the aid of some special arrangement in the mercury.

The Rectifier Switch.

The arc which forms the conducting medium for the current from the transformer phases to the D.C. load is extremely mobile, and now with the aid of control grids can be dispersed rapidly, causing the circuit to be made discontinuous without actual mechanical rupture. When the grids have become polarised negatively, and de-ionisation has taken place, the resistance of the circuit through the rectifier is infinite, and it will withstand an E.M.F. of many times the working value. Though it is not possible to influence the arc at the anode on which it is burning, the next anode can be prevented from taking it over by applying the negative bias. If all the grids are energised instantaneously, commutation of the arc will cease, and the voltage at the cathode will fall away to zero, following closely the decreasing voltage on the anode. The load being no longer energised, the cathode gradually takes up the negative potential of the circuit and becomes dead. Any reactive energy in the circuit, such as will exist when switching off a short circuit or heavy fault will be dissipated in the rectifier itself, where it cannot burn or destroy any contacts or surfaces. The heat equivalent of this energy will be absorbed by evaporating

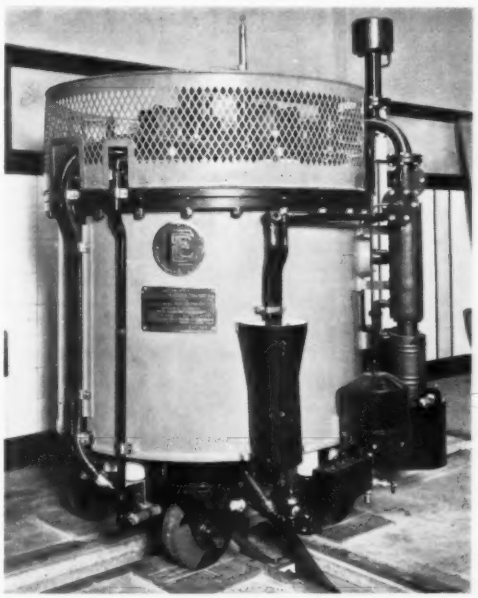


Fig. 6. 1,000-ampere Grid-controlled Rectifier.

mercury, which is again quickly condensed and returned to the cathode, the heat being carried away in the water or other cooling medium.

Fig. 7 shows in diagram form a scheme of connections for this purpose. The high-speed relay may be energised either from the A.C. or D.C. systems connected to the rectifier, and it may either close on rate of change of current or at a predetermined current value.

Fig. 8 illustrates the rapidity with which this protection can operate on a short circuit. A rectifier delivering 2,340 amperes at 795 volts was used for this test, and the arc was cleared in .02 second. A high-speed relay so arranged and operating from the A.C. side, will enable the rectifier to protect itself and its transformer against its own misdeeds, and interrupt a backfire so quickly that there is no evidence of it having occurred. Though backfires are now very rare in modern well-designed rectifiers operating within their rated load, conditions which cause a backfire, such as excessive overloads, may arise from time to time ; grid-controlled switching can clear them immediately, even when other plant is running in parallel. This protection is very valuable, and eliminates the reverse current circuit breaker, which is much more expensive to install and maintain.

For traction systems this form of protection can be arranged to operate only on a backfire or a very high overload, with a result that a fault on the track which is cleared by a circuit breaker on the feeder concerned does not operate the grid

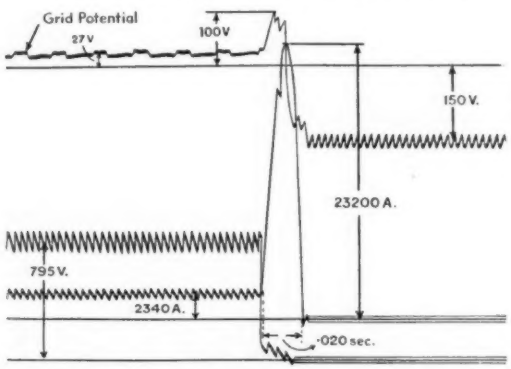


Fig. 8. Oscillogram illustrating Rapidity of Interruption by Grid Control.

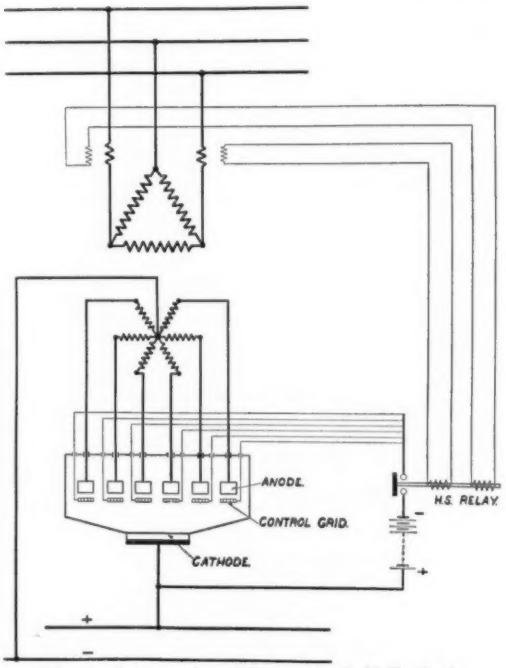


Fig. 7. Interruption of Current by Grid Excitation.

biassing relay, but if the fault is such as to cause a heavy overload on the rectifier itself, the grid bias can be applied whilst the circuit breaker is opening. Being very much quicker than the oil switch on the A.C. side, it will considerably reduce the shock to the transformer and the whole of the A.C. system. Where it is advisable the relay can be arranged to re-set itself very quickly, and allow the rectifier to carry on with its normal duties, only locking the rectifier out after reclosing two or three times and finding the fault still persisting. The supply of power to the substation busbars need not be cut off for more than about 1/10th to 1/4th of a second at a time, and the interruption will be scarcely noticed in practice. Switching of power by means of the grids is a very valuable new feature, and may well have a great influence on the development of rectifiers for very high D.C. voltages.

Voltage Regulation.

Voltage regulation by polarised grids is based on the fundamental consideration that the average value of the rectified voltage depends

upon the phase position in the positive half cycle of anode voltage at which the arc is commutated from one anode to the next. The later this phase position the lower is the average D.C. output voltage from the rectifier, as may be seen from Fig. 9. This diagram shows a theoretical wave form of voltage, but in practice sufficient inductance is included in the D.C. circuit to smooth out the wave form at the busbars to values which are comparable with those of the best rotating machines.

It is possible to regulate the voltage from the full voltage as determined by the transformer windings down to zero, and this range involves an angular displacement of commutation through 120°. Extending this range beyond the zero voltage point and into the negative half period of the anode results in complete switching off of the voltage, a voltmeter will give no reading whatever, and the rectifier becomes completely non-conducting.

Downward voltage adjustment does not appreciably affect the fall of D.C. volts from no load to full load, and the regulation curves are practically parallel over the whole range. In other words, the drop in the D.C. terminal volts remains the same in value, and the percentage regulation is inversely proportional to the ratio of no load voltage to the maximum voltage.

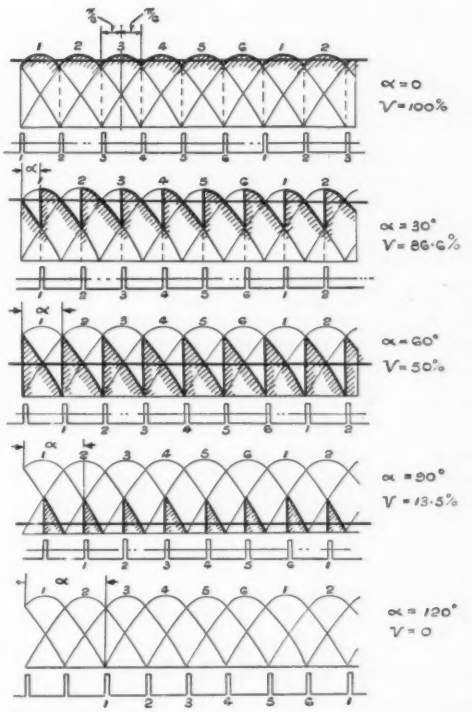


Fig. 9. Variation of average D.C. voltage with Phase Angle of Anode Commutation.

The range of voltage adjustment is greater than can be obtained from any rotating machine except the compensated D.C. generator, and complete stability is provided under all conditions. By virtue of its control grids the mercury-arc rectifier can supply any machine or apparatus requiring variable D.C. voltage, whilst itself connected to an A.C. supply of constant voltage and frequency. It provides a simple means of controlling the speed of D.C. motors fed from an A.C. system, and can give traction rectifiers a level compound or overcompound characteristic. The apparatus is simple and small and lends itself to automatic control with the use of equipment of an entirely static nature.

Inversion of Direct to Alternating Current.

Inverted running naturally implies the existence of machinery in the D.C. circuit having a back E.M.F. and capable of maintaining a voltage at the rectifier terminals for some appreciable period. A feed back of power can be obtained if the average D.C. voltage of the rectifier is lower than the busbar volts, and the grid control adjusted to ignite the arc during the reverse polarity of the anodes.

Fig. 10 shows the voltage conditions in the rectifier and its external circuit during regeneration. The anode voltage must be rising towards its maximum negative value when the arc is ignited, and the peak value must be greater than the D.C. voltage, in order that the arc may be extinguished. The connections to the D.C. load must, of course, be reversed, as it is fundamental that the current should flow through the rectifier in the normal direction. The arc is maintained by the D.C. system, the voltage of which provides the arc drop, and also overcomes the transformer

E.M.F. In the transformer windings the currents will flow in opposition to the alternating E.M.F.'s, which, in fact, now become the back E.M.F.'s of the system. The diagram is drawn to conform to the same conditions as Fig. 1, which applies to a rectifier of 100 volts. All A.C. E.M.F.'s being now back E.M.F.'s are given negative polarity, and the connections to the load are reversed. Operation of the arc is maintained as in rectification by the cathode being more negative than the anodes, a condition which is equivalent to the anodes being positive relative to the cathode. The assumed arc drop of 25 volts leaves the average anode potential 75 volts negative.

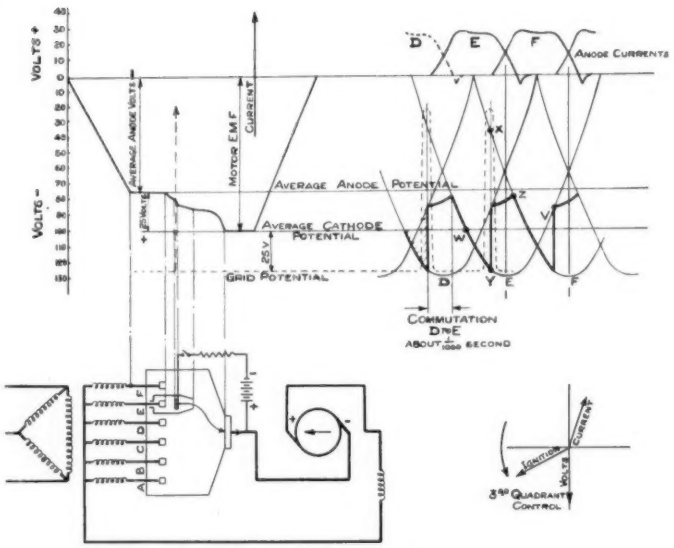


Fig. 10. Voltage Distribution in Rectifier and external circuit during Regeneration.

The grid impulse for anode F is given at X, but the arc is not immediately transferred to it from anode E. A period of about one-thousandth of a second is required for commutation and de-ionisation, with the result that both anodes E and F are in operation over the period YZ. At W, anode E becomes more negative than the cathode, and the arc tends to be extinguished, but inductance carries it on to Y, where F begins to take it over and carries it completely at Z. Anode E must then be blocked by the grid-bias to prevent re-ignition at V, where it again becomes more positive than the cathode. If re-ignition were not prevented a short circuit would develop as the transformer negative voltage declined and changed to positive, adding its voltage in series with the load.

A grid impulse starts the arc at each anode, it is extinguished by the peak of the A.C. wave, and the control grids then prevent re-ignition until the correct instant of the next negative half cycle. It is evident that inverted running of a rectifier would be quite impossible without the control of the arc, which is provided by the polarised grids. These necessary conditions are normally complied with by standard grid control apparatus which is suitable for rectification and able to give the grid impulses in the third vector quadrant.

The voltage drop in an inverted rectifier agrees closely with the values which apply to the unit when acting as a rectifier. The loss in volts on load is the same, and bears the same relation to the D.C. current. It is not dependent on the D.C. volts applied to its terminals or variations in the instant of ignition.

If the load consists of a motor which is being retarded, its voltage will be falling steadily as its speed decreases, and it is possible to follow this up by grid control of the rectifier, so that a steady current can be obtained down to zero voltage. With the aid of the control grids, the machine can be brought to a standstill. It is essential that the A.C. system should be maintained alive from some other source, as the rectifier is unable to deliver a magnetising current to the A.C. side, and, in addition, alternation of the transformer voltage is needed to provide for commutation of the arc.

Hard and Soft Control.

We have noted that the formation of the arc may be prevented or delayed by a negative

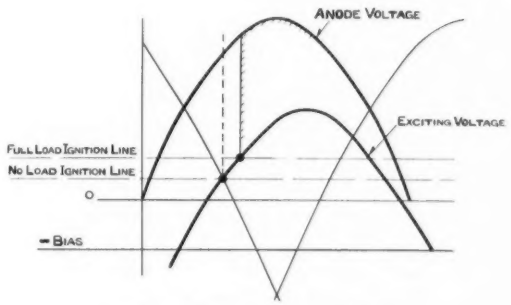
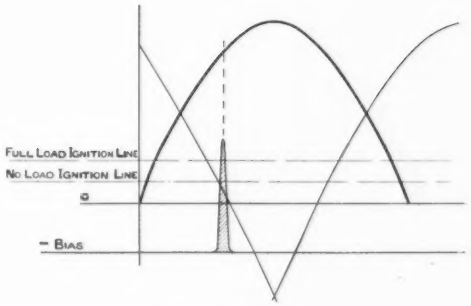


Fig. 11. Soft Control by Sine Wave.



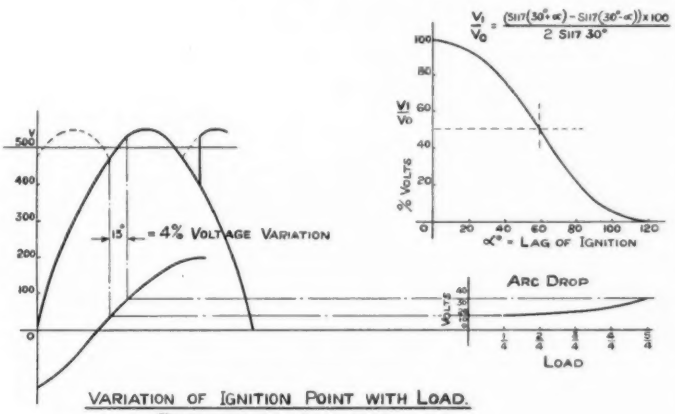
Hard Control by Impulse.

potential on the grid, and that provided the anode is positive the change of the grid polarisation will cause the arc to start. In practice this change may take place gradually, as on the slope of a sine wave, or it may be caused by a sudden impulse.

Fig. 11 shows the two methods of excitation which have been termed "soft" and "hard" control respectively.

With "hard" or "impulse" excitation the applied voltage can be made sufficiently high to determine the ignition point in spite of variations which may occur in the condition of the rectifier, and this type of control is, therefore, much more definite and precise in its operation.

Fig. 12 shows the variations which can take place in the point of ignition, due to the variation in the arc drop, and also due to the variations in temperature of the rectifier. The diagrams refer to a 500-volt rectifier having an arc drop which varies from about 17 volts at 1/4 load to 30 volts at 25 per cent. overload, and the projection of these values on to the sine wave of grid potential shows that a variation in the ignition point of 15° will result. The later ignition with increasing load causes a reduction in rectifier voltage of as much as 4 per cent., in addition to the normal regulation which is determined chiefly by



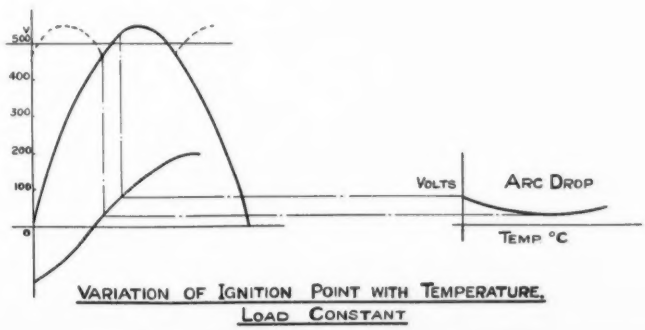


Fig. 12. Variations of Ignition due to Arc Drop.

transformer reactance and C.R. drop. Similar variations can take place due to temperature conditions, as shown in the bottom diagram of this figure. These diagrams are sufficient to show that "soft" control is only approximate, but that in practice it adversely affects the voltage regulation. It will also be appreciated that if the wave form of the grid potential varies slightly, it may cause further irregularities of the voltage control. None of these disadvantages are present when the "impulse" type of ignition is used, because the voltage impulse can be sufficiently high to ignite the rectifier at the correct instant in spite of variations in the arc drop and temperature.

METHODS OF POLARISING THE GRIDS.

(1) *Soft Methods.*—These can be sub-divided into :—

(*a*) Sine Wave.
(*b*) Inclined Potential.

(2) *Hard or Impulse Methods* include the following :—

(*c*) Synchronous Contact.
(*d*) Saturation Transformer.

(*a*) *Sine Wave Control.*

The sine method is probably the best known and most used, but its limitations and defects are now becoming more evident.

With this scheme the grids are usually maintained at a negative potential relative to the cathode by means of a battery or small metal rectifier. The positive periods are provided by a small transformer or induction regulator, delivering a sine wave of E.M.F., the peak value of which is greater than the grid-bias, with the result that the peak of the positive half wave reverses the polarity of the grid potential to a value which crosses the ignition line, and so decides the instant of formation of the arc. The ignition point can be shifted by varying the value of the grid bias, by varying the peak value of the control voltage, or shifting the grid voltage in phase relative to the anode voltage. All these alternatives suffer from the same defects, which are inseparable from soft control.

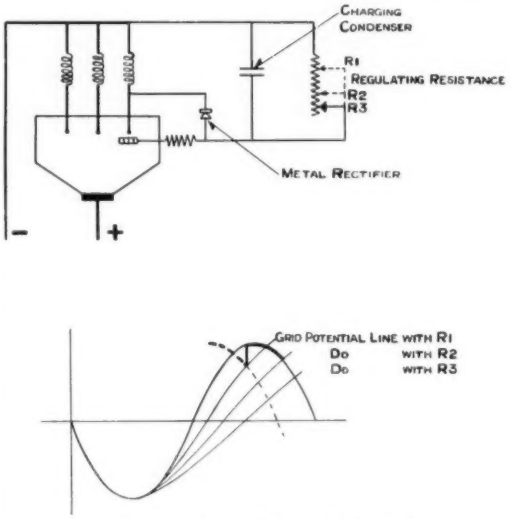


Fig. 13. Inclined Potential Control.

(*b*) *Inclined Potential Method.*

In this scheme (Fig. 13) the grids are given their negative potential by the main transformer windings, with the aid of a condenser connecting them to the neutral point or negative terminal. A metal rectifier is used to prevent the flow of charging current to the grid during the positive half cycle. This connection itself would maintain the grids at a negative potential, but a variable resistance in parallel with the condenser allows the charge to leak away during the positive half cycle of the anode, and the grid potential gradually changes its state and becomes more positive. The potential of the cathode can be considered as following the potential of the anode, which is burning at the instant considered, and the point on the inclined potential line where it intersects the voltage curve of this anode, determines the instant of ignition and commutation of the arc. A variation of this system is illustrated by Fig. 14, and this gives good results for small units. In this case the biassing voltage is positive, and the inclined potential curve of the grid crosses the line of ignition voltage at an instant which is determined by the voltage setting on the regulating potentiometer. The greater the positive bias the higher the voltage delivered by the rectifier.

(c) *Synchronous Contact System.*

This system makes use of a rotating contact driven by a synchronous motor, and is shown diagrammatically in Fig. 15. The grids are given negative bias by one of the usual methods, and their potential is changed to positive in correct sequence by a rotating brush passing over the contacts on a stationary disc. To advance or retard the ignition point, the disc carrying the contacts may be displaced by hand or automatic means.

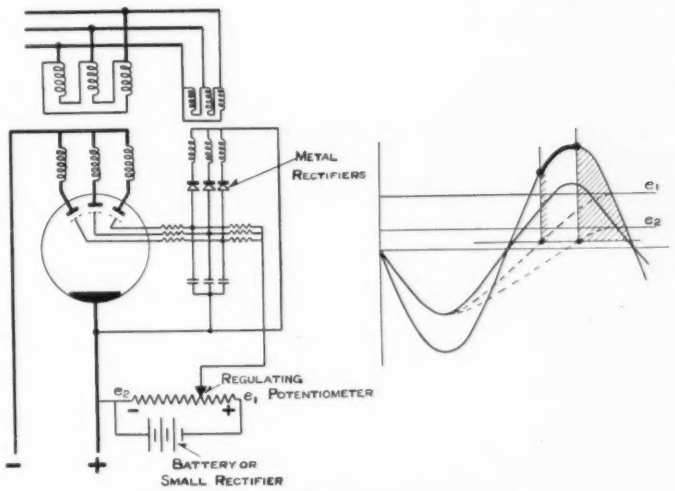


Fig. 14. Inclined Potential Control System..

An alternative arrangement, which is purely electrical, makes use of shifting the effective flux relative to the centre line of the poles in the rotor of the synchronous motor. For this purpose the synchronous motor field is provided with two windings situated at right angles to one another, and by strengthening or weakening one or other of these, the rotor can be advanced or retarded, relative to the rotating field of the stator. This method is in use on a large number of installations, and for many large rectifiers of the steel-tank type.

Fig. 16 shows a synchronous contact apparatus for compounding a 500 kW. rectifier from 450 to 500 volts. In this case the disc is advanced to give earlier ignition as the D.C. current output increases, with the aid of a small motor coupled by worm gear to the disc, and controlled by a compounding relay.

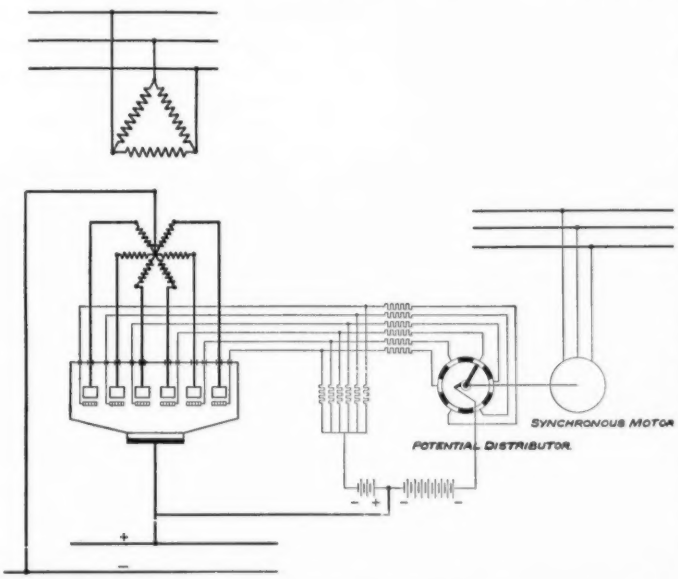


Fig. 15. Equipment for Controlling Grid Excitation of Variable-voltage Rectifier.

(d) *Saturated Transformer Control.*

A static method of control which is now used by the English Electric Company makes use of a small highly saturated transformer for impulsing the grid. One transformer is used for each anode, see Fig. 16. These small transformers have magnetic circuits of high permeability material, and are each provided with two exciting windings, one of them being connected in star and the other in delta. One secondary winding is provided

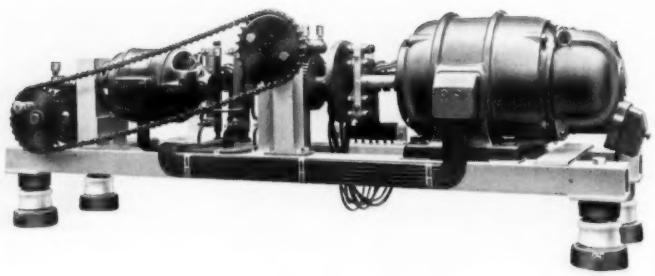


Fig. 16. Synchronous Control Gear.

and connected in circuit with the grid-bias and the anode grids.

The back E.M.F. in the magnetising coils is negligible, and the ampere turns are determined by the value of the resistance in each circuit. Due to the high saturation in the transformers, flat topped waves of flux are induced; consequently there is no rate of change of flux and no E.M.F. induced in the coils, except at the instant when the resultant ampere turns pass through zero. The sudden reversal of the flux at this instant induces a peak of voltage, having a duration of about 10°, and these positive peaks superimposed on the negative grid-bias are sufficient to ignite the arc. The A.C. ampere turns on one limb of each transformer are usually of constant value, and the other ampere turns 150° out-of-phase are varied by adjusting the resistance in series with them at their star point. By this means the phase angle of the resultant ampere turns and flux can be changed and the instant of ignition can be adjusted, giving simple and reliable "hard" control of the rectifier. Saturation transformer type of control lends itself readily to automatic working and compounding by the D.C. current. It gives instantaneous adjustment of voltage without the time lag inseparable from mechanical movements.

The arrangement adopted for compounding is shown in Fig. 17, and further illustrated in Fig. 18. In this case the variable ampere turns of each impulse transformer are determined by choke coils which are given D.C. saturation from the source of potential which provides the grid-bias. The compounding coils which measure the direct current output are fed from a divertor in the D.C. power circuit, and reduce the saturation as the load increases. The impedance of the choking coil, therefore, decreases with increasing D.C. load, and the variable ampere turns on the impulse transformers are weakened, causing the impulses to move back and ignite the arc earlier. This scheme is ideal for compounding a traction or other load, as it is instantaneous in its action, and no parts require a mechanical movement. Load sharing of any number of rectifiers is assured by the use of an equaliser connection, as in a D.C. machine or rotary converter. The divertor resistance in the D.C. circuit is little more than an ammeter shunt and consumes negligible power.

Ripples and Smoothing.

The D.C. voltage delivered by a rectifier is not perfectly uniform, but contains ripples or harmonics superimposed on its mean value. The

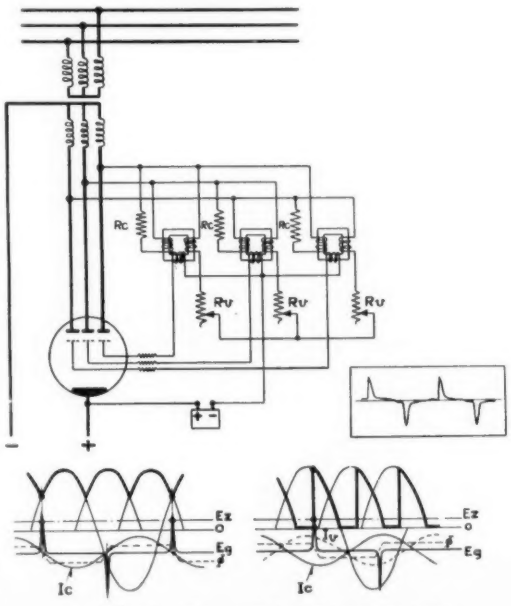


Fig. 17. Saturated Transformer Control.

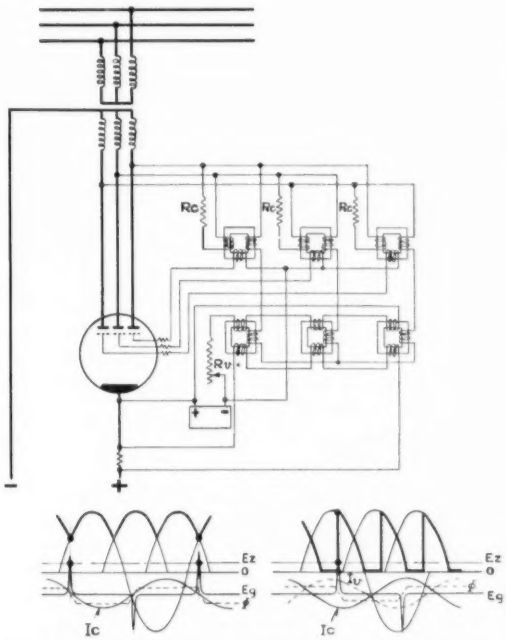


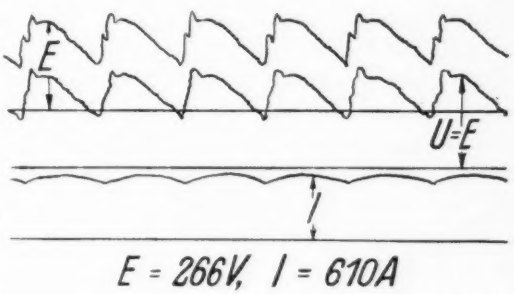
Fig. 18. Saturated Transformer Control with Compounding.

amplitudes of these various harmonics are determined chiefly by the transformer reactance, and the frequencies which exist are usually multiples of the number of rectifier phases and the periodicity of the A.C. system.

A rectifier without grid control or one with such control but operating at its full voltage at 50 cycles impresses ripples of 300, 600, 900 and 1,200 cycles on its D.C. wave form, together with higher frequencies which are of insignificant amplitude. For a 6-phase rectifier running on 50 cycles and on no-load, these ripples have r.m.s. values of approximately 4 per cent., $\frac{1}{2}$ of 1 per cent., and a $\frac{1}{4}$ of 1 per cent. respectively.

Fig. 19 shows the D.C. voltage wave and current given by a 6-phase rectifier of 300 volts, with the voltage reduced to 266 by grid control. The voltage wave follows closely the shape of the anode wave, and the current is undulating. Inductance in the D.C. circuit reduces the amplitude of each harmonic, and it is usual to include a cathode choke or smoothing reactor in the rectifier outfit for this purpose. The effect of the cathode choke is shown in Fig. 20, and it will be noted that considerable improvement has taken place. The values of all the harmonics can be evaluated in sine terms for the different frequencies, and over the whole range of voltage regulation from the maximum to zero and for any number of rectifier phases. A typical range of curves connecting the output voltage with the amplitude of each harmonic up to 48 times the supply frequency is given in Fig. 21 for a 6-phase rectifier. It will be noted that when the D.C. voltage is reduced to 80 per cent. of its maximum value, the harmonic with the largest amplitude which corresponds with 300 cycles has its r.m.s. value increased from 4 per cent. to 14 per cent., and the higher harmonics have increased in similar proportion. Some of those which were insignificant when the rectifier was delivering its maximum voltage may now become of importance and capable of causing interference in communication circuits.

A cathode choke will not deal effectively with the ripple voltages under all conditions of load. The cathode choke is, in effect, an A.C. choke operating at the ripple frequencies, and is magnetised by the D.C. load. Its smoothing effect, therefore, decreases as the D.C. load decreases. Since the effective resistance of the D.C. system increases with decreasing load, it is necessary to provide paths of low impedance to the residual harmonics if the same degree of smoothing is to



E = D.C. Voltage of Rectifier. I = Current.

U = ,, ,, ,, ,, after smoothing.

Fig. 19. Oscillograms of Rectifier without Smoothing Equipment operating at Reduced Voltage by Grid Control.

be maintained at small loads. This is accomplished by providing a shunt circuit consisting of a reactor and a condenser tuned for resonance at the frequency of the ripple. The limiting impedance at resonance is the ohmic resistance of the shunt, and this is designed to pass the residual harmonic current, which would otherwise flow into the D.C. system. A cathode choke having a certain inductance will, therefore, produce a greater degree of smoothing if tuned shunt circuits are present, and, moreover, this degree of smoothing is maintained down to very low loads. Apparatus of this kind can be provided to reduce the amplitude of any or all the harmonics to any required degree. The results obtained by the use of a good smoothing system are illustrated in Fig. 22, which, like Fig. 19 and Fig. 20, shows the voltage wave before smoothing and after smoothing, and the current delivered from a 300-volt 6-phase rectifier operating at about 86 per cent. of its maximum D.C. voltage. One tuned shunt circuit is required for each frequency, together with the series reactor or cathode choke.

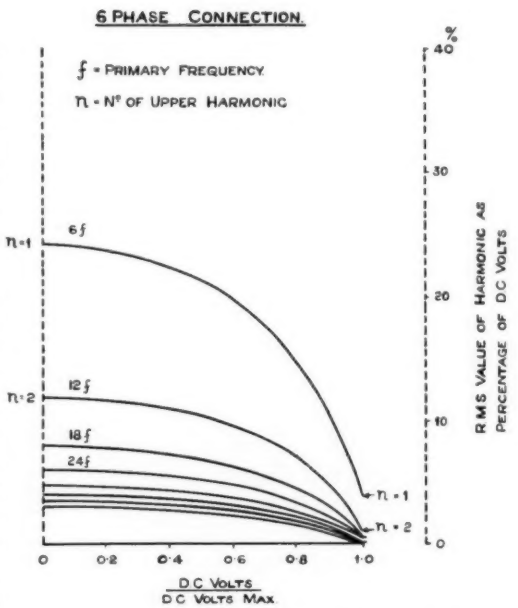


Fig. 21. Curve showing amplitudes of Ripples from Grid-controlled Rectifier.

In practice either two or four of these circuits are usually provided for dealing with the 300 and 600-cycle ripples or the range of frequencies from 300 cycles to 1,200 cycles respectively in the case of a rectifier without grid control. Four resonant shunts will usually be satisfactory in connection with a grid-controlled rectifier, which has its voltage compounded to the extent of 10 per cent. by means of the control grids, but in cases where wide voltage ranges are required additional tuned circuits may be necessary.

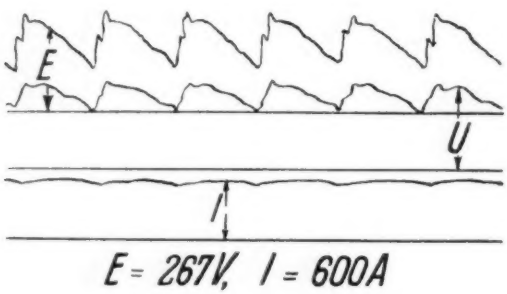


Fig. 20. Oscillograms of Voltage and Current Waves with Smoothing Reactor only.

Rectifiers supplying electrolytic processes and similar systems are usually operated at about their full load continuously, and in such cases the required degree of smoothing can be obtained by a cathode choke without the use of resonant shunts.

There are many industrial applications of rectifiers where no telephone or other interference can exist, and in these cases smoothing circuits are quite unnecessary. In certain other installations, if interference does occur, it can be eliminated by re-arranging the telephone system, which will generally be found much less costly than the provision of the resonant circuits.

It has recently been established that a well-designed traction motor will behave satisfactorily when provided with current from an unsmoothed rectifier installation, even if the ripple content of its current is as high as 30 per cent., a figure which can never occur in practice except in cases of single-phase rectifiers.

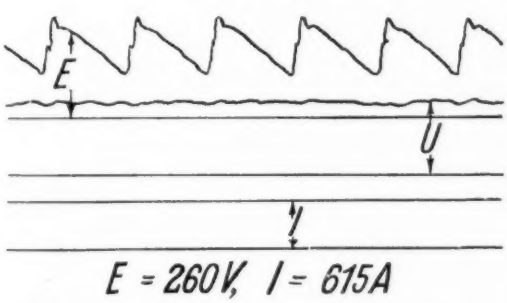


Fig. 22. Oscillograms of Voltage and Current Waves with complete Smoothing Equipment.

At present there are no approved standards for the degree of smoothing, but each case must be decided on its merits. It appears probable that these conditions will be improved in the near future, and that definite standards of smoothing for different duties will be agreed upon.

Power Factor.

The power factor conditions on the A.C. side of a rectifier or invertor are of an entirely different nature from those which exist in a more conventional circuit. The current wave is angularly displaced relative to the voltage, and it has a non-sinusoidal form. The power factor must take account of the small increases in the r.m.s. current due to each of these conditions, and is, therefore, made up of two distinct factors. These are known as " displacement " factor and " distortion " factor respectively, and the true power factor is numerically equal to their product.

The displacement factor is governed chiefly by transformer reactance in a normal rectifier, and on a grid-controlled rectifier is influenced by the point of ignition of the arc. On the other hand, the distortion factor is determined by the number of phases and the arrangement of the secondary windings, and varies from about .95 to almost unity with the different methods of transformer connection.

Referring again to displacement factor and the effect of grid control on its value, some indication of the changes which occur are given in the oscillograms Fig. 23, which show the waves of anode current and voltage for a rectifier operating on reduced D.C. voltage during rectification, and also during inverted running. In both cases the centre of gravity of the current half wave no longer coincides with the peak of the voltage wave and the displacement can be clearly seen.

Overlapping of the current on two or more anodes and interlinking of the transformer phases give a resultant current wave in the primary, which approaches more or less to sine form, but in all systems of connection some displacement still remains, together with a certain amount of distortion. It will be noted that the displacement is lagging during rectification and leading on the voltage during inverted running. In neither case is there any component at 90° to the voltage wave, and there can, therefore, be no magnetising or de-magnetising effects. As the ignition is displaced to a later point on the voltage wave, the displacement factor decreases and approaches zero at zero volts, whilst the distortion factor shows very little change, the nett result being that the displacement factor of a grid-controlled rectifier is practically equal to the fraction of the D.C. volts which is being delivered at the terminals. Thus, if a 500-volt unit is delivering 300 volts D.C., its power factor will be in the neighbourhood of .6, though the actual demagnetizing current taken from the supply system may be negligible.

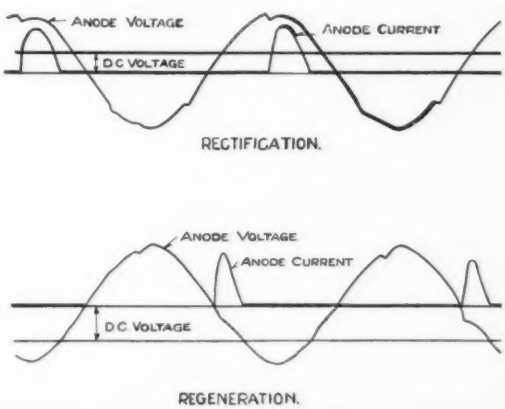


Fig. 23. Anode Currents and Voltage Waves.

For all practical purposes the power factor of a rectifier on full load is of the order of .93 to .96, but during inverted running these values cannot be approached, and the maximum power factor possible is in the neighbourhood of .88. This reduction is due to the necessity of commutating the arc before the peak value of the anode is reached. An inverted rectifier of 1,500 kW. and 500 volts will operate on a power factor of about .82. This figure includes the effect of magnetising current together with the two other factors.

In the majority of cases where grid-controlled rectifiers are installed to give voltage variation on the D.C. side, these power factor changes are of little importance, since they do not involve any serious increase in the magnetising currents in the system. Further, as the D.C. voltage is reduced the load on the rectifier in kW. is generally reduced in proportion. Consequently, there is no increase in the kVA. loading of the transformer or supply system through the action of the control grids.

Future Developments and Applications.

The control of the arc by simple and reliable means has rendered the rectifier the most versatile of all converting machines, and the successes already achieved suggest remote and wide developments in the use of the electron stream in an atmosphere of suitable gas for many purposes, such as switching, regulating and relaying of power.

Researches relating to the rapid de-ionisation of the arc path and instantaneous transfer of the current from one anode to another are proceeding with a view to the development of inverted rectifiers converting direct current to high frequency alternating current. Success has been achieved so far up to about 1,000 cycles, and 3,000-cycle units are at present under construction for experimental purposes.

Referring to practical developments in rectifier equipments, during the last twelve months many new applications have been made of rectifiers and rectifier groups, using the principles outlined above. Rectifier units of considerable power are protected from damage due to short circuits and faults by the instantaneous blocking action of the control grids; they are also provided with a compound characteristic in addition to the regulation of the D.C. voltage, in spite of rapid variations on the A.C. supply.

The use of rectifiers for the speed control of D.C. motors has been extended into the rolling mill field, and with two rectifiers coupled to the busbars with their polarities reversed relative to one another, an ideal arrangement can be made to take the place of the variable voltage motor generator set in the Ward-Leonard system, with greatly increased overall efficiency. An installation of this type controlling a rolling mill of 100 H.P. is in regular operation, and rectifier equipments to supply reversible rolling mill motors or winder motors of over 1,000 H.P. are contemplated.

In the fields of high tension D.C. up to the limits for which it has been developed, the rectifier is unrivalled, and a solution to the problem of the high tension direct-current transmission of power appears to be in sight. The rectifier, acting as convertor, voltage regulator and circuit breaker at each end of the line, can carry out all these duties with reliability and very high efficiency.

Frequency changing and phase conversion by entirely static means has also been developed, and rectifiers are now in service converting 3-phase, 50 cycles to $16\frac{2}{3}$ cycles single-phase, and at the same time providing the single-phase circuit with the magnetising current required to maintain it in operation.

The rectifier locomotive is already in being, and has taken two or three distinct forms; the most promising scheme, however, incorporates a single-phase rectifier on the locomotive supplying current at variable voltage to D.C. motors. This system can also regenerate the power back to the line during the periods when the motors are being retarded. All control is carried out by polarised grids on the rectifier, and the usual losses associated with resistance control are eliminated.

Many of these features are not yet commercial, but all are in course of development.

New Diesel-Electric Rail Coach for Branch Line Working.

Fig. 1. 200 h.p. Diesel-Electric Coach on the Warwick-Daventry-Northampton Branch of the L.M.S. Railway.

One striking feature in the developments of recent years in railway transport is the use of motive power other than steam. Of the alternatives the diesel-electric rail coach has been the subject of much consideration, because it has quite definitely proved its value for particular conditions. It is impossible, however, to lay down hard and fast rules, each case has to be decided on its own merits, and upon the conditions prevailing, and the requirements of the service.

The English Electric Company's part as pioneers in the development of electric traction needs no special emphasis, and their equipments are to be found giving satisfactory service in all parts of the world. So far as the Company's experience in internal-combustion engined vehicles is concerned, it is necessary only to mention that in addition to many 40 h.p. petrol-electric locomotives, which were supplied by the Dick, Kerr Works, during the War period, they have also supplied equipments for 100 h.p. petrol-electric rail coaches to the Uruguay State Railways; a 50-ton 100 h.p. petrol-electric breakdown locomotive to the Montreal Harbour Commissioners; and complete 200 h.p. diesel-electric rail coaches for the Venezuela Central Railway. They have supplied electrical equipments for 200 h.p. diesel-electric rail coaches for the San Sebastian-Pamplona Railway in Spain; and in conjunction with Messrs. Armstrong-Whitworth & Co., Ltd., have provided the electric control and motor equipments for the three diesel-electric mobile power-house engined trains, and for the diesel-electric locomotive which were put into service this year on the Buenos Aires Great Southern Railway. It may be also mentioned here that 100 h.p. petrol-engined rail coaches and

300 h.p. locomotives, with mechanical transmission, have been supplied through the Drewry Car Company to the Bermuda Railway.

The success attending the efforts of The English Electric Company in perfecting new developments in diesel-electric transport is well exemplified in the new diesel-electric rail coach described and illustrated in this article. The vehicle in its entirety was designed and built within the works of the Company ; the coach and bogies at the Dick, Kerr Works, Preston ; the engine at the Willans Works, Rugby ; and the electrical equipment at the Phœnix Works, Bradford. Preliminary running tests of the vehicle were made on the Company's test track at Preston. Thus it will be seen that The English Electric Company is in an unique position, being able to build the complete vehicle within their own works, which ensures that full and continuous attention can be given to all details, an advantage which can be readily appreciated.

The coach is particularly designed for branch line working, and is arranged to haul a standard 27-ton (tare) trailer coach.

The general appearance of the vehicle is shown in the frontispiece and Figure 1 ; whilst Figure 2 indicates the general layout. The main particulars of the vehicle are as follows :—

Length over buffers	62 ft. 10½ in.
Length over body	59 ft. 6 in.
Width over all	8 ft. 11⅝ in.
Height over all	12 ft. 11½ in.
Seating capacity as at present arranged	53
Maximum seating capacity ...	61
Weight, in working order, but without passengers or baggage	37½ tons
Maximum speed	60 m.p.h.

COACH AND BOGIES.

The body is built up on an underframe of rolled steel sections, riveted together, well braced and gussetted. The underframe bolster at the engine-end is of novel construction ; it is specially built to eliminate vibration, and has a swing bolster carried by four swing links, with nests of steel spiral springs and rubber shock absorbers. The bogie under the engine compartment is of plate frame construction, and carries the two axle-hung driving motors. The trailing bogie is built up of steel sections, and both bogies are fitted with S.K.F. roller bearing axle-boxes. The body framework and the outer panels—and the mouldings for securing them—are of steel, and the supporting pillars have ash fillings.

The coach comprises five compartments ; the engine-room ; a driving compartment at each end ; the passenger compartment ; and a luggage room ; the layout is shown in Figure 2. The engine-room, which is of steel throughout, is separated from the passenger compartment by the luggage room ; and the bulk-head on the side nearest the passenger compartment is lined with sound-deadening material, thus noise from the engine does not reach the passengers. The roof of the engine-room can be removed to enable the power unit to be lifted out bodily for major overhauls ; should sufficient head-room not be

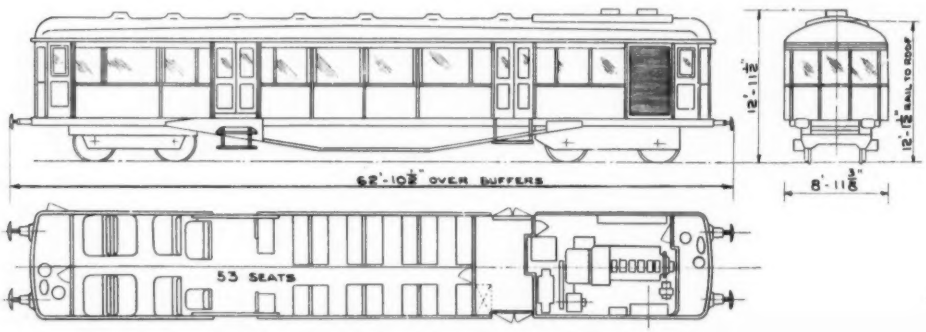


Fig. 2. Showing General Arrangement of the Rail Coach.

available to allow this method of removal the end of the coach-body can be removed, and this permits the withdrawal of the power unit on rollers.

A view of the passenger compartment is shown in Figure 3. The interior finish is of hand-polished mahogany and bubinga, with mahogany mouldings, and the metal fittings are chromium-plated. The seats are upholstered in figured moquette, and have removable cushions. The present arrangement of the seats provides for 53 passengers, but by a variation of the seating arrangements 61 passengers can be accommodated. Access to this compartment is afforded by a centre entrance controlled by sliding doors.

At the trailing-end of the coach, the partition separating the passenger and driving compartments is of glass above the waist-line ; in effect, this gives the advantages of an observation saloon since a view can be obtained through the end of the coach. Blinds are provided to cover the window for night driving.

The coach is provided with a vacuum brake operating on all wheels, and a screw-down hand-brake operating through the power brake rigging applies a brake on the wheels of the driving bogie. An electrically-driven exhauster is provided and located in the engine-compartment.

Fig. 3. Interior of Passenger Compartment.

Power Unit and Control Equipment.

The engine is a vertical 4-stroke cold-starting mechanical-injection diesel engine having six cylinders each 6 in. × 8 in., and develops 200 h.p. at 1,500 r.p.m. with a maximum output of 220 h.p. for 15 minutes ; alternative speeds of 1,200 r.p.m. and 900 r.p.m. can be obtained when the full output is not required. In design and manufacture it embodies the knowledge gained from some 27 years experience in building diesel engines of all types and sizes up to 3,500 h.p.

The engine is water-cooled, and the circulation of the water through the radiator and jackets is effected by means of a centrifugal pump driven from the crankshaft of the engine. An oil-cooler, through which the lubricating oil is circulated and cooled, is incorporated in the radiator.

The speed at which the engine runs is controlled from the master controller located in the driving cab, the system by which the control is effected being patented. In this system, the same oil as that used for lubricating the engine, is used under pressure in control cylinders to make any required variation in the governor control spring settings, or in the timing ; the oil valves are solenoid-operated. If the oil pressure should fail at any time the engine is shut down automatically.

The engine is direct coupled to a 135 kW. generator, designed, built and rated in accordance with traction practice. The exciter, which is separately mounted, is chain-driven. This arrangement reduces the overall length of the complete unit to a minimum. The combined set is illustrated in Figure 4, and it will be seen that the engine and generator are carried in trunnions arranged to give a three-point suspension. In this way stresses are prevented in the crank-case or crank-shaft, due to any whipping or strain in the coach underframe. The arrangement enables the usual heavy bedplate to be dispensed with ; and also eliminates the necessity to provide for special rigidity in the coach underframe. The power unit bearers and their fixing bolts are

insulated from the underframe with rubber, and this reduces any noise or vibration transmitted along the coach, to a minimum.

The control equipment, comprising reverser, motor contactors and the battery auto-cutout apparatus, is grouped together and conveniently mounted on a framework above the generator; the connections between this apparatus and external cables are facilitated by the provision of terminal bars. This simplifies disconnection and dismantling for overhaul or other purposes, since the entire control equipment on its framework can be removed as one unit. Figure 5 shows a view of the engine compartment looking towards the generator end.

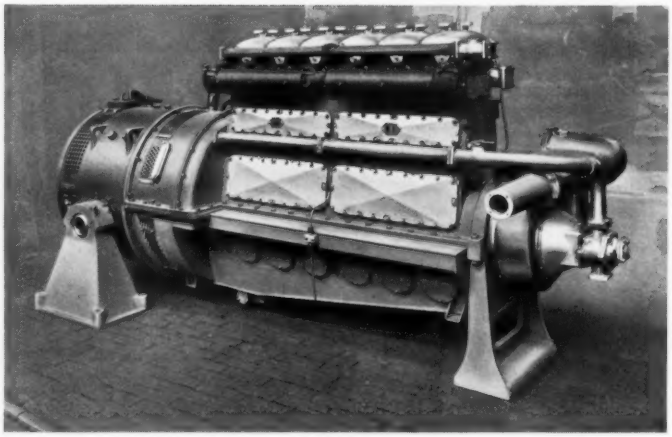


Fig. 4. 200 h.p. 1,500 r.p.m. Diesel Engine direct coupled to 135 kW. Generator.

HEATING EQUIPMENT.

The means for providing adequate heating for the coach, and for a possible trailer, was the subject of full consideration. A steam heating system was finally preferred to the more obvious methods, electric heating or exhaust heating, for example, for the following reasons. An electric heating system, although requiring only light and simple equipment, or an exhaust heating system, would have necessitated running the engine light when standing in stations, or when coasting, in order to obtain constant heating and even temperature. It would have been necessary also to run the engine before going into service so as to pre-heat the coach. In addition, with an electric heating system it would not have been possible to provide heating for an ordinary steam-heated trailer coach.

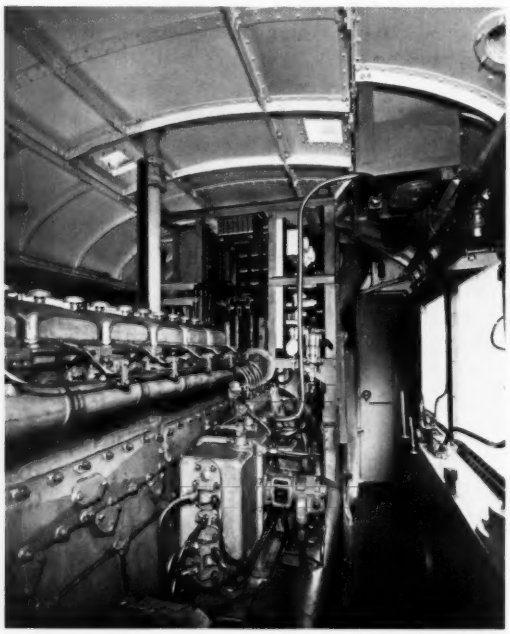


Fig. 5. View of Engine Compartment.

As previously indicated a low pressure steam heating system is provided, and steam is supplied from an oil-fired boiler, the burner for which uses the same fuel as the engine. Radiators are fitted under the seats in the passenger compartment, and after circulating through these the steam is returned as condensate to the boiler through a feed-tank. A boiler feed pump forms part of the equipment, and the operation of this is controlled automatically by the water level in the boiler. Occasional replenishment of water in the feed tank is, of course, necessary to make good any losses. If the water in the boiler reaches the limiting low-level, or if the flame from the

oil burner for the boiler is extinguished accidentally, the oil supply to the burner is cut off automatically. Standard hose-couplings are fitted at each end of the coach, so that steam can be supplied to any standard steam fitted passenger coach which it may be desired to use as a trailer.

Operation.

The engine compartment requires no attendance during running. The vehicle is arranged for one-man operation. Control is extremely simple, and drivers quite new to this type of vehicle have been able to take over control after less than one hour tuition. Figure 6 shows a view of one of the driving compartments.

The engine is started by operating a push-button switch, one of which is located in each driving compartment. This sets up the circuit between the generator and the battery, and the generator runs as a motor and drives the engine, until the latter starts and takes on the drive. After starting, the master controller gives complete control of all operations, the engine speed can be advanced from idling to 1,500 r.p.m. in three steps, and finally weakens the traction motor field ; by moving the handle of the master controller backwards, the engine speed can be reduced, but the weak motor field condition is retained until the idling position on the master controller is reached. Thus economy of engine-power, combined with maximum electrical output, is obtained. Further economy in running costs can be secured by moving the master controller handle to the engine shut-down position during coasting periods and when standing in stations, etc. It should further be noted that the engine can be shut down by the master controller, which has the usual " dead-man " button incorporated.

Excessive overload currents are prevented by the arrangement of the generator windings and by control of the excitation; and thus the engine itself cannot be overloaded. The full power output of the generator is maintained constant automatically, over a wide range of train speed, it is therefore unnecessary for the driver to watch any instruments while driving.

A set of signal lights consisting of two red and two white lights is provided in each driving compartment. The white lights indicate that the pressure of the lubricating oil is adequate, and that the water circulation is correct. The red lamps glow to give a warning signal both in the event of failure of the services mentioned, and also to indicate when the engine is shut down.

Fig. 6. One of the Driving Compartments.

Service Results.

By the courtesy and co-operation of the L.M.S. Railway the rail coach has been in operation under service conditions on portions of the L.M.S. Railway system.

The first period of running was on the Warwick-Daventry-Northampton branch ; the coach running as a single unit carrying passengers or with trailing loads, such as cattle-trucks, horse-boxes, etc., as required. Vehicles of the type exemplified here are available for work 23 hours per day ; but for the period of running mentioned the coach was in service 15 hours per day for 5 days per week. This arrangement was made to suit the convenience of the Railway Company so as to fall in line with the existing time tables.

During five weeks, ending November 11th last, the rail coach ran 5,880 miles with an average

RUNNING DATA. WARWICK–DAVENTRY–NORTHAMPTON SERVICE.

Date Week Ending	Solo Miles	With Trailer Miles	Total Miles	Approx. Total Ton/Miles	Fuel Oil Engine Galls.	Fuel Oil Boiler Galls.	Total Galls.	Engine Fuel Miles per Gall.	All Fuel Miles per Gall.	Engine Fuel Lbs./ton Miles
14/10/33	1014	146	1160	48270	193.0	44.0	237.0	6.00	4.90	.0356
21/10/33	995	168	1163	48664	198.4	38.0	236.4	5.85	4.92	.0360
28/10/33	1094	129	1223	45020	183.8	34.25	218.05	6.65	5.60	.0360
4/11/33	997	173	1170	42200	182.8	31.0	213.8	6.4	5.46	.0380
11/11/33	1021	142	1163	42540	181.9	39.5	221.4	6.4	5.30	.0375

engine fuel consumption of 6.26 miles per gallon (or 5.22 miles per gallon if the fuel for the heating system is taken into account). The oil for the heating-system works out at 0.5 gallons per hour of coach service. These figures include the mileage and engine running times during incidental service, such as shunting at wayside stations and shed movements. The accompanying table gives further details of the results obtained during this trial period.

At the present time the coach is in service coupled to a standard trailer-coach (tare 27 tons), on the Watford-St. Albans service, see Figure 7, and for this purpose the trailer coach has been fitted with a driving-end.

From the information obtained on these trials, it is interesting to record that the steps taken to avoid the transference of noise and vibration from the engine compartment to the passenger compartments, were entirely successful; the smooth acceleration, and good riding qualities of the coach have caused very favourable comment.

Fig. 7. Diesel-Electric Coach coupled to Standard Trailer Coach.

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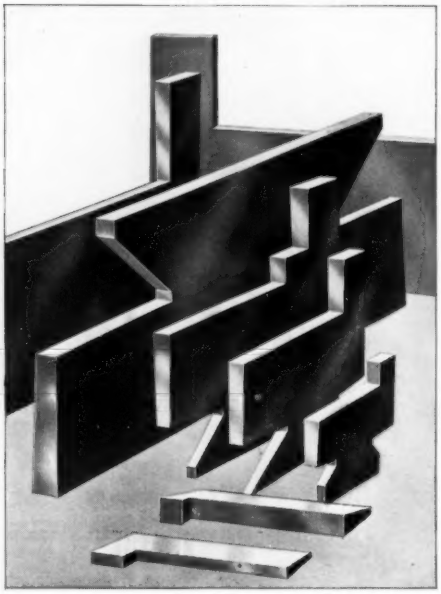

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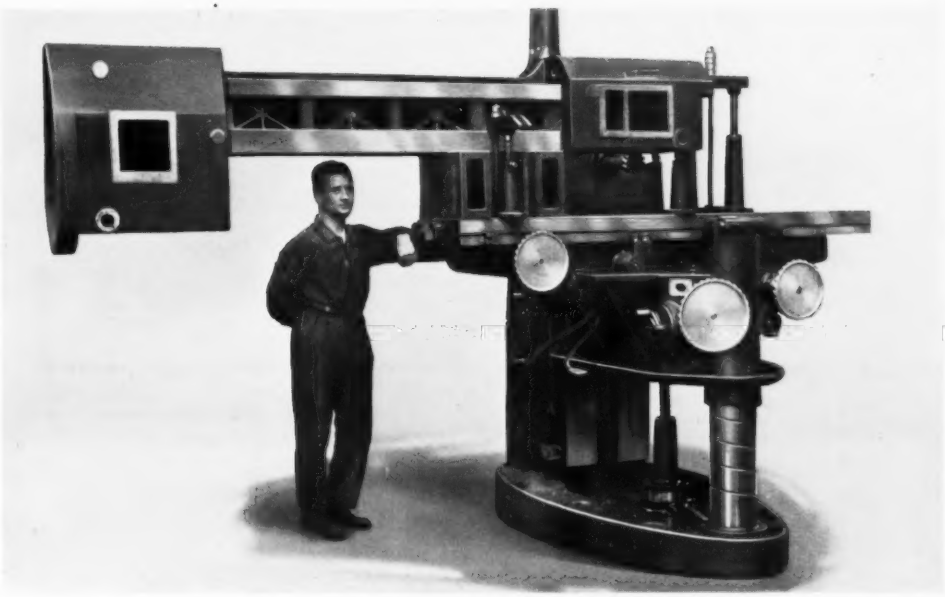

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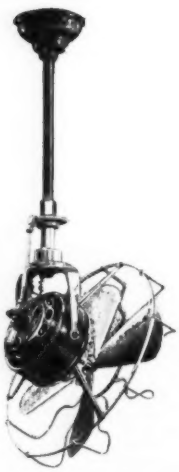

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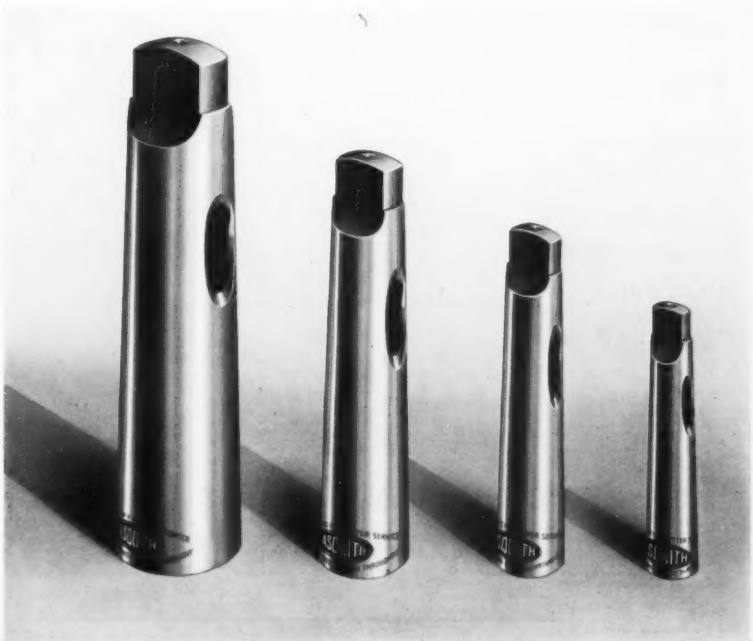

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